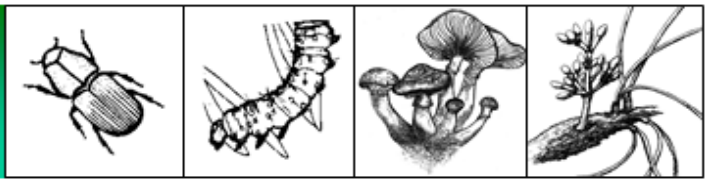
Forest Health Protection



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2019 Revised R1 Forest Insect Hazard Rating System User Guide for use with Inventory Data Stored in FSVeg and/or Analyzed with the Forest Vegetation Simulator (FVS)

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INTRODUCTION

Forest insects and diseases are important disturbance factors in forest ecosystems. Insect and disease activity may dramatically alter the structure, composition, and age class distribution of forested stands and may interfere with a manager's ability to achieve established objectives.

As part of the Northern Region (R1) Integrated Restoration and Protection Strategy, Forest Health Protection (FHP) entomologists devised bark beetle and defoliator hazard ratings for inventory data, such as from stand exams and Forest Inventory and Analysis (FIA) plots. These hazard ratings are available to assist land managers in three ways: 1) as keyword files that can be used with the Forest Vegetation Simulator (FVS) to determine current hazard and model hazards over time, with or without management or disturbances; 2) hazard ratings are calculated during the post-load process and stored in FSVeg tables; and 3) hazard ratings are available in the R1 Summary Database Analysis tools. This document discusses these forest insect hazard ratings, how they are derived, and how they may be used to assist land managers with planning.

Since the original publication of this report (Randall and Bush 2010), modifications were made to the mountain pine beetle in lodgepole pine hazard rating logic, and a combined host pine beetle hazard rating was developed (Randall et al. 2011). Further modifications were completed since the 2011 update to clarify that a minimum 40 square feet of basal area of host type is required for a hazard rating to be assigned a moderate or higher rating (Randall et al. 2018) (see Appendix 9 in this document for justification of this criteria). Since the 2018 update, we have added two hazard ratings for ponderosa pine based on Egan and others (in press), and made some clarifications and adjustments on the combined host pine beetle hazard rating and the whitebark pine and limber pine host for mountain pine beetle hazard rating.

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Hazard Ratings

Forest insects require three things to cause significant impact to resource values: susceptible hosts; insect populations; and favorable weather conditions. Hazard rating systems measure the susceptibility of forested areas to a particular insect by evaluating the degree to which sampled tree and stand-level characteristics are conducive to successful insect colonization and reproduction. High and moderate hazard forested areas are more likely to experience significant mortality if challenged by insect populations when weather conditions are favorable.

Data Considerations

When using hazard ratings in a landscape analysis (broad- [Regional assessments], mid- [Forest assessment], and base- [Project assessment] levels) (Nelson et al. 2015), it is assumed that available data are a representative sample of landscape conditions. A spatially balanced inventory across the geographic area of interest can be used to derive estimates of hazard, however, small forested areas, or areas with unique characteristics, may not be represented or have insufficient data for analysis. Users should carefully evaluate available data for a particular analysis area to ensure that a representative sample of current forest conditions exists. Hazard ratings calculated for a sampled area assumes that forest conditions in the sample area are homogeneous; if excessive variability in any of the parameters used to calculate hazard ratings occurs within the sampled area, the hazard rating may not accurately reflect the hazard. If that is the case, further stratification of the geographic area of interest into various dominance types, size classes, and densities may be needed.

Hazard ratings applied to stand exams will accurately reflect the stand at time of inventory. It is important to consider the age of the exam data when interpreting hazard. Many stand characteristics used to calculate hazard may have changed since the time of the exam. If data needs to be modeled to current condition, then FVS and the associated hazard rating keyword files, should be used to model hazard to a contemporary inventory date and the assumptions and keyword files used documented in the project file. As always, it is prudent to ground check results.

Hazard Rating Maps

The integration of database and geographic information system (GIS) software enables mapping of forested areas by their insect and/or disease hazard rating. These maps of stand susceptibly enable managers to identify concentrations of high- and moderate-hazard, or determine the composition of hazard levels across a landscape (e.g. Steed et al. 2019).

Large, contiguous forested areas of high insect hazard promote epidemic forest insect populations by providing large areas of quality food. When high-hazard areas are small and intermixed with low-hazard areas, forest insect populations are not as likely to grow and cause significant resource impacts. Low-hazard areas have host species for a particular insect, but the host is not of high enough quality and/or in large enough quantity to allow forest insect populations to build substantially. Forest insects may still cause significant mortality in the host components of low-hazard forested areas in a landscape, but losses will be lower than in a landscape where high-hazard forested areas occur across a number of contiguous acres.

Appropriate Use of Hazard Maps

Spatial depictions of hazard are powerful tools for managers and planners at the broad-, mid-, and base-levels. Such maps help managers identify areas that have the highest probability of significant forest insect activity. Although hazard ratings do not predict when insects will damage resources, experience has shown that forest insects are most likely to occur where there are abundant high hazard forested areas (Williams et al. 2018). Hazard ratings address the quality and quantity of food available, but do not address insect populations. Therefore, additional information would be necessary to assess risk and predict loss.

Keep in mind the methods used to develop a hazard map. Many times the accuracy of the data is unknown. This does not mean hazard maps generated from such data are not useful, but it is necessary to acknowledge data limitations and to explain to map consumers how data quality may affect the accuracy of the hazard map. If developed correctly, using current spatial and tabular data of known accuracy, hazard maps can identify areas with the largest preponderance of stands susceptible to forest insect outbreaks. Furthermore, due to stand/polygon heterogeneity, not every tree or plot within a high hazard polygon may be susceptible to a given forest insect.

Understanding relationships of dominance type, size class, and canopy cover to various forest insect hazard ratings assists with developing forest insect hazard maps. Tools have been developed by the R1 vegetation analysis team to understand the relationships of vegetation classification attributes used in R1 (Barber et al. 2010) to the resulting hazard ratings. These relationships can then be applied to existing vegetation layers such as R1-VMap, FSVeg Spatial, or a hybrid of the two. Furthermore, other spatial information such as maps designating wildlife habitat, wildland urban-interface, potential vegetation, long-term climatic trends (such as downscaled, 30-year mean drought index), treatment opportunities, etc. can be integrated when developing these coverages to provide additional hazard rating data or planning criteria.

Project Planning

A hazard map is the easiest way for managers to quickly identify areas with the highest likelihood of significant forest insect activity. However, more information will be needed to plan management activities in project areas. At the project level the heterogeneity of stands will be important in overall landscape hazard.

The manager should also consider the current level of insect activity in the area. Current insect activity is the magnitude of an insect population affecting a forested area as determined by the number of currently infested trees and their proximity to the stand being assessed. Insect activity is a dynamic variable and may change quite suddenly due to factors such as adverse or favorable weather conditions, or immigration and emigration of insects. For this reason insect activity should be reviewed every year or two.

Additional information from a variety of sources, including recent walkthrough assessments, plot-level model runs (Forest Insect and Disease Tally system [FINDIT]) (Bentz 2000, McMahan et al. 2019), aerial photographs and insect aerial detection surveys should be gathered to help better characterize stand conditions and insect activity when determining which areas are most critical for treatment. Hazard ratings are provided for individual stands/ plots and do not account for the importance of the landscape scale context. Landscape-scale distributions of susceptible forest conditions can provide habitat where insect populations may amplify to levels that can overwhelm benefits from stand-level hazard reduction treatments (Schmid and Mata 2005).

Ways to Alter Hazard: Management Considerations

Hazard can be altered through silvicultural practices that break up large, homogeneous blocks of susceptible forest that can host major insect and disease populations (Williams et al. 2018). Specific silvicultural practices to reduce hazard vary with the insect involved.

By using FVS and associated keywords for hazard ratings, various silvicultural prescriptions can be evaluated. Immediate and long-term effects for various management scenarios can be compared to see how they affect a given insect-caused hazard over time.

Insect Hazard Rating Systems Available to Region 1

Region 1 FHP staff formulated forest insect hazard rating systems based on research which identified site and stand characteristics associated with areas, which experienced high levels of forest insect activity. Each insect hazard rating system and a reference section of supporting literature is included in its own appendix at the end of this document.

The hazard ratings were derived specifically to be used with commonly collected tree and stand-level attributes with the fewest variables and least amount of biological complexity possible. For some insects, hazard ratings exist that incorporate additional factors (such as tree age, growth rates, or elevation) that may provide more accurate assessments. Information on these other ratings are noted in the references for each insect, and many are found in the updated FINDIT program (McMahan et al. 2019). Region 1 hazard ratings are calculated by looking at a combination of site and stand characteristics and assigning a relative index value in terms of susceptibility to the insect. Susceptibility can be considered as the amount of quality host (i.e. host species of size classes that support reproductive success) and stand densities that create resource competition (i.e. tree stress) and favorable microclimates for insect (e.g. for pheromone communication). Thresholds for these host and stand traits are incorporated into the index values. By multiplying the index values, a composite score is calculated, and the composite score is assigned a hazard rating. In the subsequent rating system descriptions for the individual insects, the following formula is used.

Multiplicative Index Score = Criteria A rating * Criteria B rating * Criteria C rating

Each hazard rating system was translated into a Forest Vegetation Simulator (FVS) (Dixon 2002) event monitor keyword set which calculates hazard using the original criteria in the published hazard rating system then summarizes hazard into 1 of 4 possible classes:

- ☐ VL or 0 = Very Low (little to no host species but forested)
- ☐ L or 1 = Low Hazard
- ☐ M or 2 = Moderate Hazard
- ☐ H or 3 = High Hazard

These summary ratings (0, L, M, H) are displayed in FSVeg for R1 data, available in the R1 Summary Database Analysis tool, and can be output by FVS.

The hazard criteria for the following insects (**acronyms**) and host combinations are in this document:

- spruce beetle (**SB**) (*Dendroctonus rufipennis*) (Appendix 1)
- Douglas fir beetle (**DFB**) (*Dendroctonus pseudotsugae*) (Appendix 2)
- mountain pine beetle (**MPB**) (*Dendroctonus ponderosae*) and western pine beetle (**WPB**) (*Dendroctonus brevicomis*) in ponderosa pine (Appendix 3)
- mountain pine beetle (**MPB**) (*Dendroctonus ponderosae*) in western white pine (Appendix 4)
- mountain pine beetle (**MPB**) (*Dendroctonus ponderosae*) in lodgepole pine (Appendix 5)
- mountain pine beetle (**MPB**) (*Dendroctonus ponderosae*) in whitebark pine/ limber pine (Appendix 6)
- pine bark beetles (**MPB** and **Ips** spp.) (*Dendroctonus* and *Ips* species) in combined host (Appendix 7)
- western spruce budworm (**WSBW**) (*Choristoneura occidentalis*) and Douglas-fir tussock moth (**DFTM**) (*Orygia pseudotsugae*) in Douglas fir and true firs (Appendix 8)
- bark beetles (**MPB, WPB, Ips** spp.) in ponderosa pine (Appendix 10)

Please note **BA** = basal area, **DBH** = diameter breast height, **BAwtDBH** = basal area weighted diameter, **QMD** = quadratic mean diameter. All metrics are in English units.

Conclusion

The use of landscape hazard rating maps for forest insects will assist managers in determining the potential for these disturbance agents to interfere with a manager's ability to reach established objectives. By identifying areas in the landscape with a preponderance of high hazard conditions prior to insect outbreaks, managers have an opportunity to reduce hazard through silvicultural prescriptions, or to determine if action is warranted. Tools which look at hazard, from landscape (broad- mid- or base-level) hazard maps to an individual stand's hazard rating (Nelson et al. 2015), allow managers to proactively promote insect resistance by altering hazard conditions instead of reacting to insect activity.

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APPENDIX 1: SPRUCE BEETLE

Spruce beetle (**SB**) outbreaks cause extensive tree mortality and modify stand structure by reducing the average spruce tree diameter, height, and stand density. Residual trees are often slow-growing small and intermediate sized trees, which eventually become dominant. In the Rocky Mountain West, Engelmann spruce is the species most often impacted.

Stand Conditions Conducive To Infestations

Endemic SB populations usually live in wind-thrown trees. When populations increase to high levels in downed trees, beetles may attack susceptible, large diameter standing trees. Most outbreaks originate in wind-thrown trees. Once beetle populations reach high levels, more relatively healthy trees are attacked.

In mature stands, larger diameter (≥18inches DBH) trees usually are attacked first. If an infestation persists in a stand, smaller diameter trees may be attacked.

In the Rocky Mountain area, susceptibility of a stand to SB attack is based on the physiographic location, tree diameter, BA, and percentage of Engelmann spruce in the overstory. Engelmann spruce stands are highly susceptible if they grow on well-drained sites in creek bottoms, have an average DBH of 16 inches or more, have a BA greater than 150 square feet per acre, and have more than 65 percent spruce in the overstory. Since stand physiographic location is not captured in inventory data, it was omitted in the hazard calculation but could be added when evaluating specific stands within a project-area or generating a hazard map.

Interpreting Hazard

High hazard stands are those in which large amounts of spruce mortality can be expected once a SB outbreak occurs. Moderate and low hazard stands may experience less beetle-caused mortality; but individual large, old spruce might still be killed. When high-hazard stands are intermixed with low-hazard stands, beetle populations may not be as active. Low hazard stands may have spruce, but are either not of high enough quality or in large enough quantity to allow SB populations to remain at high levels. SB may still cause significant mortality in the spruce component of low-hazard stands in a landscape, but losses will be lower than in a landscape where high-hazard stands are clustered.

Hazard Criteria for Spruce Beetle[1]

Criteria	Attribute	Low (.5)	Moderate (2)	High(3)
A	QMD of Engelmann spruce ≥10" DBH	<12"	12"≤ QMD < 16"	≥16"
B	BA ft^2/acre all species, all sizes	<100 ft^2/ac	100 ≤ BA < 150 ft^2/ac	≥150 ft^2/ac
C	% of total BA that is Engelmann spruce ≥10" DBH	<50%	50% ≤ % BA < 65%	≥65%

Directly Calculated Hazard Values and Hazard Rating Multiplicative Index

Hazard	Calculated Values	Hazard Rating
Very Low	0	0, VL
Low	<2	1, L
Moderate [1]	2-17	2, M
High [1]	≥18	3, H

[1]For stands/plots with < 40 ft^2 total BA, hazard is rated as 'Low' due to reduced bark beetle habitat suitability at low stand densities (Appendix 9)

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APPENDIX 2: DOUGLAS-FIR BEETLE

Douglas-fir beetles (**DFB**) normally kill small groups of Douglas-fir trees, but during outbreaks mortality of up to 100 trees are not uncommon. Outbreaks last in duration from two to four years. Those of longest duration coincide with periods of drought.

Stand Conditions Conducive To Infestations

At low or endemic levels, the DFB infests scattered trees, including windfalls and trees injured by fire scorch, defoliation, or root disease. Where such susceptible trees are abundant, once they have been infested and killed, beetle populations can build up rapidly and spread to adjacent green, standing trees. Damage is greatest in dense stands of mature Douglas-fir. Various fungi introduced by the DFB also contribute to mortality of infested trees.

Interpreting Hazard

High-hazard stands are those in which large amounts of Douglas-fir mortality is expected once a DFB outbreak occurs. Moderate- and low-hazard stands may experience less beetle-caused mortality, but individual large, old Douglas-fir trees might still be killed.

When high-hazard stands are intermixed with low-hazard stands, DFB populations may not be as active. Low hazard stands may have Douglas-fir, but either not of high enough quality or in large enough quantity to allow DFB populations to remain at high levels. DFB may still cause significant mortality in the Douglas-fir components of low-hazard stands in a landscape, but losses will be lower than in a landscape where high-hazard stands are clustered.

The likelihood of a DFB infestation developing within a stand is related to the proportion of susceptible Douglas-fir and overall stand density. Generally, DFB attacks are most successful on Douglas-fir trees that are mature or over-mature, large in diameter, and are growing in more densely stocked stands. A very high stand density may increase the susceptibility of younger and smaller diameter Douglas-fir trees. The higher the proportion of trees with susceptible characteristics, the higher the susceptibility of the stand to DFB attack.

Hazard Criteria for Douglas-fir Beetle[1]

Criteria	Attribute	Low (.5)	Moderate (2)	High(3)
A	QMD for Douglas-fir $\geq$ 9" DBH	<10"	10" $\leq$ QMD < 14"	$\geq$14"
B	BA ft^2/acre all species, all sizes	<100 ft^2/acre	100 $\leq$ BA < 250 ft^2/acre	$\geq$250 ft^2/acre
C	% of total BA that is Douglas-fir $\geq$9" DBH	<50%		$\geq$50%

Directly Calculated Hazard Values and Hazard Rating Multiplicative Index

Hazard	Calculated Values	Hazard Rating
Very Low	0	0, VL
Low	<2	1, L
Moderate [1]	2-17	2, M
High [1]	$\geq$18	3, H

[1]For stands/plots with < 40 ft^2 total BA, hazard is rated as 'Low' due to reduced bark beetle habitat suitability at low stand densities (Appendix 9)

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APPENDIX 3: MOUNTAIN PINE BEETLE /WESTERN PINE BEETLE / PINE ENGRAVERS IN PONDEROSA PINE

Ponderosa pine is susceptible to a number of tree killing bark beetles including mountain pine beetle (MPB) and western pine beetle (WPB). Although MPB and WPB are the beetle species most likely to impact mature stands of ponderosa pine, several pine engravers (*Ips pini* and other *Ips* species) may associate with these primary species in a bark beetle complex.

Stand Conditions Conducive to Infestations

Bark beetles respond to stressed ponderosa pine. Stands most susceptible to bark beetle attacks have a high composition of susceptible host or dense stands comprised of large diameter ponderosa pine. There are some subtle differences in ponderosa pine stands susceptible to MPB and those susceptible to WPB, but for the purpose of analysis, we have combined these beetles in the hazard rating criteria.

Interpreting Hazard

Hazard is defined by two factors, the quality and the quantity of susceptible ponderosa pine. The quality of the ponderosa pine component of a stand as a MPB or WPB food source is best characterized by stand density and phloem thickness. Since ponderosa pine phloem thickness is not generally measured in most inventories, DBH and other available stand characteristics are used as surrogates. The quantity of the food source refers to the species composition and density of the forest. A pure, well stocked ponderosa pine stand will be more likely to support a large MPB population than a mixed species and/or poorly stocked stand.

When high-hazard stands are surrounded by low-hazard stands, beetle populations may not be as significant. Low-hazard stands may have ponderosa pine, but are either not of high enough quality or in large enough quantity to allow beetle populations to remain at high levels. Beetles may still cause significant mortality in the ponderosa pine components of low-hazard stands in a landscape, but losses will be lower than in a landscape where high hazard stands are clustered.

Hazard Rating Criteria for Bark Beetles in Ponderosa Pine[1]

Criteria	Attribute	Low (.5)	Moderate (2)	High(3)
A	QMD of ponderosa pine≥5" DBH	<6"	6" ≤ QMD < 10"	≥10"
B	BA ft^2/acre all species, all sizes	<80 ft^2/acre	80 ≤ BA< 120 ft^2/acre	≥120 ft^2/acre
C	% of total BA that is ponderosa pine ≥5" DBH	<40%	40% ≤ % BA< 65%	≥65%

Directly Calculated Hazard Values and Hazard Rating Multiplicative Index

Hazard	Calculated Values	Hazard Rating
Very Low	0	0, VL
Low	<2	1, L
Moderate [1]	2-17	2, M
High [1]	≥18	3, H

[1]For stands/plots with < 40 ft^2 total BA, hazard is rated as 'Low' due to reduced bark beetle habitat suitability at low stand densities (Appendix 9)

NOTE: The hazard rating for ponderosa pine given in Appendix 10 is currently recommended over this rating.

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APPENDIX 4: MOUNTAIN PINE BEETLE IN WESTERN WHITE PINE

Until about 80 years ago western white pine was the most abundant forest type in the Northern Rocky Mountain area. The causes of change include mountain pine beetle (**MPB**), fire suppression, and past harvesting. The primary agent of change, however, is white pine blister rust (*Cronartium ribicola*). White pine blister rust continues to kill most white pine trees that regenerate naturally and white pine blister rust and bark beetles continue to kill remaining large trees. Maintaining stands of white pine that remain is a high priority.

Stand Conditions Conducive To Infestations

Based on historical accounts of past MPB outbreaks, we know that dense stands (greater than 140 square feet per acre BA) with a large component (> 60 percent stand BA) of large diameter (QMD >8inch DBH) white pine trees sustain the greatest losses to MPB.

Interpreting Hazard

High hazard is defined by two factors, the quality and the quantity of susceptible western white pine. The quality of the western white pine component of a stand as a MPB food source is best characterized by stand density and phloem thickness. Since western white pine phloem thickness is not generally measured in inventories, DBH and other available stand characteristics are used as surrogates. The quantity of the food source refers to the species composition and density of the forest. A pure, well stocked western white pine stand will be more likely to support a large MPB population than a mixed species and/or poorly stocked stand.

When high-hazard stands are intermixed with low-hazard stands, MPB populations may not be as significant. Low-hazard stands may have western white pine, but are either not of high enough quality or in large enough quantity to allow beetle populations to remain at high levels. MPB may still cause significant mortality in the western white pine components of low-hazard stands in a landscape, but losses will be lower than in a landscape where high-hazard stands are clustered.

Hazard Criteria for Mountain Pine Beetle in Western White Pine[1]

Criteria	Attribute	Low (.5)	Moderate (2)	High (3)
A	QMD white pine ≥5" DBH	<8"	8" ≤ QMD < 12"	≥12"
B	BA ft^2/acre all species, all sizes	<80 ft^2/acre	80 ≤ BA < 120 ft^2/acre	≥120 ft^2/acre
C	% of total BA that is white pine ≥5" DBH	<25%	25% ≤ % BA < 50%	≥50%

Directly Calculated Hazard Values and Hazard Rating Multiplicative Index

Hazard	Calculated Values	Hazard Rating
Very Low	0	0, VL
Low	<2	1, L
Moderate [1]	2-17	2, M
High [1]	≥18	3, H

[1]For stands/plots with < 40 ft^2 total BA, hazard is rated as 'Low' due to reduced bark beetle habitat suitability at low stand densities (Appendix 9)

Reference

Hagle, S., Johnson, T., Stipe, L., Schwandt, J., Byler, J., Kegley, S., Bell Randall, C., Taylor, J., Lockman, B., Sturdevant N. 2000. Successional functions of pathogens and insects; ecoregion sections M332a and M333d in northern Idaho and western Montana. Volume 1: Methods. Forest Health Protection Report 00-10. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 39-42 p.

APPENDIX 5: MOUNTAIN PINE BEETLE IN LODGEPOLE PINE

Mountain pine beetle (**MPB**) attacks and kills lodgepole pine. Epidemics frequently develop in lodgepole pine stands that contain well-distributed, large- diameter trees. When outbreaks are extensive, millions of trees may be killed each year. During epidemics, widespread tree mortality can alter the forest ecosystem.

Stand Conditions Conducive To Infestations

Susceptible lodgepole pine stands are dense (≥100 square feet per acre BA) and have a large component (≥50 percent BA) of large diameter (QMD ≥8 inches DBH) lodgepole pine. Outbreaks may be limited if stand BA is high enough to effectively limit individual tree diameter and phloem thickness to levels that prevent successful MPB reproduction (Safranyik and Carroll 2006).

In the original hazard rating system, stand elevation and trees per acre were also incorporated into the hazard rating calculation. After careful analysis of resulting hazard ratings, we determined that the model for MPB in lodgepole pine provided more consistent and appropriate results if the previous criteria of trees per acre 3 inches DBH or larger (Randall et al. 2010) was dropped. Elevation was also eliminated as a warming climate is expected to alter elevation thresholds.

Interpreting Hazard

Hazard is defined by two factors, the quality and the quantity of susceptible lodgepole pine. The quality of the lodgepole component of a stand as a MPB food source is best characterized by stand density and phloem thickness. Since lodgepole pine phloem thickness is not generally measured in inventories, DBH and other available stand characteristics are used as surrogates. The quantity of the food source refers to the species composition and density of the stand. A pure, well stocked lodgepole pine stand will be more likely to support a large MPB population than a mixed species and/or poorly stocked stand. The location of a stand also has a bearing on MPB success.

When high-hazard stands are intermixed with low-hazard stands, MPB populations may not be as active. Low-hazard stands may have lodgepole pine, but are either not of high enough quality or in large enough quantity to allow beetle populations to remain at high levels. MPB may still cause significant mortality in the lodgepole pine components of low-hazard stands in a landscape, but losses will be lower than in a landscape where high-hazard stands are clustered.

Hazard Criteria for Mountain Pine Beetle in Lodgepole Pine[1]

Criteria	Attribute	Low (.5)	Moderate (2)	High(3)
A	QMD of lodgepole pine ≥5" DBH	<7"	7" ≤ QMD < 8"	≥8"
B	BA ft²/acre all species, all sizes	<80 or ≥250 ft²/acre	80 ≤ BA < 120 ft²/acre	120 ≤ BA < 250 ft²/acre
C	% of total BA that is lodgepole pine ≥5" DBH	<25%	25% ≤ % BA < 50%	≥50%

Directly Calculated Hazard Values and Hazard Rating Multiplicative Index

Hazard	Calculated Values	Hazard Rating
Very Low	0	0, VL
Low	<2	1, L
Moderate [1]	2-17	2, M
High [1]	≥18	3, H

[1]For stands/plots with < 40 ft² total BA, hazard is rated as 'Low' due to reduced bark beetle habitat suitability at low stand densities (Appendix 9)

References

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APPENDIX 6: MOUNTAIN PINE BEETLE IN WHITEBARK PINE/ LIMBER PINE

The high elevation five-needle pines, as a group, provide essential habitat for wildlife, often being the major source of cover in high elevation environments. The range of limber pine partially overlaps with that of whitebark pine. Most recent work on mountain pine beetle (**MPB**) in high elevation pines has been centered on whitebark pine; however, much of the information appears to apply to limber pine as well.

Stand Conditions Conducive To Infestations

Historically, the principal natural mortality agent of whitebark pine was the MPB. Perkins (2003) found tree and stand-level characteristics associated with MPB attack in whitebark pine are qualitatively similar to other MPB–pine host systems, although the attack thresholds are quantitatively different. Whitebark pine stands with BAs below 44 square feet per acre and trees with QMD below 7 inches were not attacked in the early 20th century epidemic in central Idaho. These factors, and other MPB hazard information, were used to build the whitebark/limber pine hazard criteria for MPB.

Interpreting Hazard

Hazard is defined by two factors, the quality and the quantity of susceptible whitebark and limber pine. The quality of the pine component as a MPB food source is best characterized by stand density and phloem thickness. Since phloem thickness is not generally measured in inventories, DBH and other available stand characteristics are used as surrogates. The quantity of the food source refers to the species composition and density of the forest. A pure, well stocked pine stand will be more likely to support a large MPB population than a mixed species and/or poorly stocked stand.

When high-hazard stands are intermixed with low-hazard stands, beetle populations may not be as active. Low-hazard stands may have whitebark and limber pine, but are either not of high enough quality or in large enough quantity to allow beetle populations to remain at high levels. MPB may still cause significant mortality in the whitebark and limber pine components of low-hazard stands in a landscape, but losses will be lower than in a landscape where high-hazard stands are clustered.

Hazard Criteria for Mountain Pine Beetle in Whitebark and Limber Pines[1]

Criteria	Attribute	Low (.5)	Moderate (2)	High (3)
A	QMD of whitebark and limber pine ≥5" DBH	<7"	7" ≤ QMD < 12"	≥12"
B	BA ft²/acre all species, all sizes	<40 ft²/acre	40 ≤ BA < and 45 ft²/acre	≥45 ft²/acre
C	% of total BA that is whitebark and limber pine ≥5" DBH	<25%	25% ≤ % BA < 50%	≥50%

Directly Calculated Hazard Values and Hazard Rating Multiplicative Index

Hazard	Calculated Values	Hazard Rating
Very Low	0	0, VL
Low	<2	1, L
Moderate [1]	2-17	2, M
High [1]	≥18	3, H

[1]For stands/plots with < 40 ft² total BA, hazard is rated as 'Low' due to reduced bark beetle habitat suitability at low stand densities (Appendix 9)

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APPENDIX 7: PINE BEETLE IN COMBINED PINE HOST

A number of bark beetles, including **MPB**, **WPB**, and some of the more aggressive pine engraver beetles (*Ips* species) attack and kill pines (*Pinus* species). Hazard rating systems have been developed for individual host species; however these systems are not able to accurately assess the hazard of stands containing multiple pine species. It is necessary to group individual pine species components in order to accurately assess hazard.

We developed this hazard rating system by integrating the logic for the individual host species hazard rating systems presented in this document.

Stand Conditions Conducive To Infestations

Susceptible mixed pine stands are dense and have a large combined pine species component of trees greater than 6 inches DBH. This size threshold is based on an averaging of the various individual MPB hazard ratings. Most of these individual species ratings have similar thresholds for the hazard criteria. Because MPB in Region 1 is largely driven by lodgepole pine, the averaging weighted heavily to thresholds in the lodgepole pine hazard rating. In addition, stands where several pine species co-occur, lodgepole is often one of the species present.

Hazard Criteria for Mountain Pine Beetle in All Pines Combined[1]

Criteria	Attribute	Low (.5)	Moderate (2)	High(3)
A	QMD all pines ≥ 5" DBH (whitebark, limber pine, western white pine, lodgepole pine and ponderosa pine)	<6"	6" ≤ QMD < 8"	≥8"
B	BA ft^2/acre all species, all sizes	<80 ft^2/acre	80 ≤ BA < 120 ft^2/acre	120 ≤ BA
C	% of total pine BA ≥5" DBH	<25%	25% ≤ % BA < 50%	≥50%

Directly Calculated Hazard Values and Hazard Rating Multiplicative Index

Hazard	Calculated Values	Hazard Rating
Very Low	0	0, VL
Low	<2	1, L
Moderate [1]	2-17	2, M
High [1]	≥18	3, H

[1]For stands/plots with < 40 ft^2 total BA, hazard is rated as 'Low' due to reduced bark beetle habitat suitability at low stand densities (Appendix 9**)**

Interpreting Hazard

Hazard is defined by two factors, the quality and the quantity of susceptible pine. The quality of the pine component of a stand as a MPB food source is best characterized by stand density and phloem thickness. Since phloem thickness is not generally measured in inventories, DBH and other available stand characteristics are used as surrogates. The quantity of the food source refers to the species composition and density of the forest. A pure, well stocked pine species stand will be more likely to support a large MPB population than a mixed host and non-host species and/or poorly stocked stand. The location of a stand also has a bearing on MPB success.

When high-hazard stands are intermixed with low-hazard stands, beetle populations may not be as active. Low-hazard stands may have pine components, but are either not of high enough quality or in large enough quantity to allow beetle populations to remain at high levels. MPB may still cause significant mortality in the pine components of low-hazard stands in a landscape, but losses will be lower than in a landscape where high-hazard stands are clustered.

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APPENDIX 8: WESTERN SPRUCE BUDWORM/DOUGLAS-FIR TUSSOCK MOTH

Western spruce budworm (WSBW) and Douglas-fir tussock moth (DFTM) are defoliating insects, which eat the needles of Douglas-fir and true fir trees, though other species may be defoliated during epidemics. When populations of these insects reach epidemic proportions, they can cause a reduction in growth, top kill, tree mortality, and mortality of regenerating trees. WSBW outbreaks tend to last longer and cause less direct tree mortality because budworms preferentially feed on current year foliage. DFTM outbreaks tend to be shorter in duration (2-3 years), but result in more significant mortality losses because tussock moth larvae may completely defoliate a tree.

This hazard rating system is based on the presence and density of species known to be susceptible to defoliators in the Northern Region. This represents a very coarse assessment of variables commonly available within inventory data and does not depict other critical factors related to defoliation including the presence of multiple canopy layers or the relative susceptibility of true fir, Douglas-fir, and spruce hosts. Forest Health Protection recommends limited-use of these ratings. They may be beneficial as a starting point for assessment, but further site-specific forest composition and structure information is needed to accurately represent susceptibility to defoliators.

NOTE: This hazard rating has not been evaluated or updated since Randall and Bush (2010).

Stand Conditions Conducive To Infestations

Because larvae of both species disperse by moving up and out from their egg masses and spinning silken thread to balloon on the wind to a new host, they tend to be more destructive in dense (high BA) stands with a high host (Douglas-fir/true fir) component and multiple canopy layers which intercept ballooning larvae.

Interpreting Hazard

High-hazard stands are those in which a large amount of Douglas-fir and true fir defoliation is expected once an outbreak of WSBW or DFTM occurs. Moderate- and low-hazard stands may experience less defoliation and defoliator-caused growth loss, top kill, or mortality.

When high-hazard stands are intermixed with low-hazard stands, defoliator populations may not be as active. Low-hazard stands may have host species, but are either not of high enough quality or in large enough quantity to allow defoliator populations to remain at high levels. Defoliators may still cause significant mortality in the host components of low hazard stands in a landscape, but losses will be lower than in a landscape where high hazard stands are clustered.

Hazard Criteria for Western Spruce Budworm/Douglas-fir Tussock Moth

Criteria	Attribute	Low (.5)	Moderate (2)	High(3)
A	BA ft^2/acre all species, all sizes	<80 ft^2/acre	80 ≤ BA < 100 ft^2/acre	≥100 ft^2/acre
B	% of total BA that is: Engelmann spruce, subalpine fir, grand fir, and Douglas-fir ≥5" DBH	<50%	50% ≤ % BA < 80%	≥80%
C	Trees per acre ≥5" DBH	<50 /acre	50 ≤ TPA < 100 /acre	≥100 /acre

Directly Calculated Hazard Values and Hazard Rating Multiplicative Index

Hazard	Calculated Values	Hazard Rating
Very Low	0	0, VL
Low	<2	1, L
Moderate	2-17	2, M
High	≥18	3, H

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Steele, R., Williams, R.E., Weatherby, J.C., Reinhardt, E.D., Hoffman, J.T., Their, R.W. 1996. Standard hazard rating for central Idaho forests. Gen. Tech. Rep. INT-GTR-332. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 18 p.

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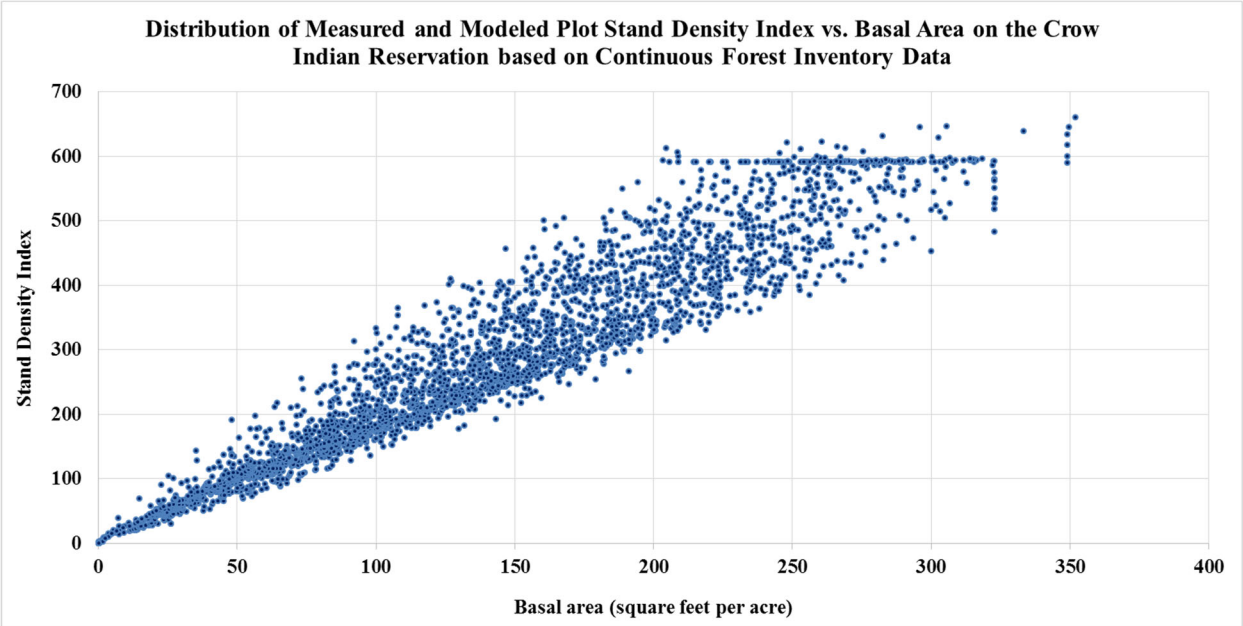
APPENDIX 9: BASIS FOR 40 SQUARE FOOT BASAL AREA THRESHOLD APPLIED TO BARK BEETLE HAZARD RATINGS.

Data were reviewed from *n* = 2,987 measured and FVS-modeled inventory plots dominated by ponderosa pines, lodgepole pines, or Douglas-fir species compositions (Egan and Hayes 2015). For these plots, the relationship between basal area ranges associated with stand density index (SDI) values were examined to derive a threshold for a 'Low' susceptibility state for ponderosa pines. Low susceptibility was identified at density levels < 150 SDI across 662 plots that were exposed to bark beetle population pressure and documented across 17 western yellow pine research studies (Egan et al. in press).

It was assumed lodgepole pine forests have similar low-density resistance based on microclimate factors. This assumption is supported by multiple studies (such as Whitehead et al. 2007) cited within a white paper summarizing mountain pine beetle treatment effectiveness (Egan et al. 2014). Similarly, this threshold was extrapolated to Douglas-fir beetle and spruce beetle based on best-available science and FHP specialist expert opinion (Schmid and Frye 1976, Negron et al. 1999).

From this analysis, we derived the threshold where anything < 40 square feet per acre of total stand basal area, and considered forested, is automatically attributed with a 'Low' bark beetle susceptibility rating. An alternate threshold of <= 50 square feet of basal area per acre was considered, but was not advised because, as SDI levels approached 200, trees would be moderately susceptible to beetle-attack (Egan et al. in press).



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APPENDIX 10: UPDATED BARK BEETLE HAZARD RATING FOR PONDEROSA PINE BASED ON STAND DENSITY INDEX

Results of Egan et al. (in press) analysis of empirical data from 17 research studies spanning 662 plots with 62,973 pines sampled in yellow pine stands indicate a strong relationship between probability of resistance during bark beetle (mountain pine beetle, western pine beetle, Jeffery pine beetle) outbreak and stand density index (SDI) (Stage 1968). This relationship was used to update the R1 hazard rating system for ponderosa pine (Appendix 3), and is applicable across the western U.S. The new system used probability of resistance vs. SDI values after stratifying research plots based on their exposure to severe or low-moderate levels of bark beetle population pressure.

Using these resistance vs. SDI equations, we determined the SDI thresholds where resistance was high (>= 85% probability of >=90% survivorship), where it was moderate (>=85% probability of >=70% survivorship), and where stand density levels are not expected to provide any degree of resistance to beetle-attack (>= 85% probability of <70% survivorship). Survivorship (or mortality) is calculated as % of PP stems >=4" DBH (Egan et al. in press).

This hazard rating is separate for low-moderate vs. severe bark beetle pressure outbreak scenarios as susceptibility varies substantially based on short-term, ambient conditions that influence beetle population pressure and outbreak severity. The primary drivers of beetle pressure include 1) environmental factors including the severity and duration of stochastic drought events (or other stressors) and 2) vegetation factors such as the landscape-scale abundance and distribution of pine reproductive habitat available to amplify bark beetle populations (Fettig et al. 2019; Restanio et al. 2019; Egan et al. in press).

It is recommended that end-users use the severe pressure scenario for most ponderosa pine stands within the Northern Region based on recent, and future-anticipated, drought severities. Conversely, the low-moderate pressure hazard ratings should be used for isolated pine stands that are surrounded by landscapes composed of other non-pine host (such as Douglas-fir) vegetation.

This resulted in the following hazard rating scheme. Note that this is not a multiplicative index as with the other ratings.

BARK BEETLE HAZARD in PONDEROSA PINE – Severe Pressure (BB_PP_SDI_HAZ_S_PRES) using SDI

Evaluation Criteria:

1. If no PP is present (any size) but "forested", then VERY LOW SUSCEPTIBILITY (0)
2. If total stand BA (all species, all sizes) (**TBA**) is <40ft2, then LOW SUSCEPTIBILITY (1)
3. If **% host BA** (*defined as PP>=5"DBH / total stand BA of all species and sizes*) is <25%, then LOW SUSCEPTIBILITY (1)
4. If PP "**size**" is <5" (*defined as BAwtDBH of PP of all sizes or QMD of PP >=5"DBH*), then LOW SUSCEPTIBILITY (1)
5. If **% host BA** is >=25% and PP "**size**" is >=5" DBH, then hazard assignment by SDI:
    - If SDI <= 100 (all species, all sizes), then LOW SUSCEPTIBILITY (1)
        - defined as having >=85% probability of <=10% mortality or [>=90% survivorship] during severe outbreak/BB population pressure
    - If 100 > SDI < 144 (all species, all sizes), then MODERATE SUSCEPTIBILITY (2)
        - defined as having >=85% probability of <=30% mortality or [>=70% survivorship] during severe outbreak/BB population pressure
    - If SDI >=144 (all species, all sizes), then HIGH SUSCEPTIBILITY (3)
        - defined as having >=85% probability of >30% mortality [or <70% survivorship] during severe outbreak/BB population pressure

SDI Hazard Rating Criteria for Bark Beetles in Ponderosa Pine assuming Severe Pressure[1]

Criteria	Attribute	Very Low	Low	Low	Low	Moderate	High
Step 1	% of total stand BA that is ponderosa pine ≥5" DBH	0	<25% of BA *[but species present, any size]*	≥25% *OR* <5"	≥25% AND ≥5"		
Step 2	QMD of PP ≥5" DBH Or BAwtDBH of all PP						
Step 3	SDI of all trees, all sizes, in stand				≤ 100	100 < SDI < 144	≥144

[1]For stands/plots with < 40 ft^2 total BA, hazard is rated as 'Low' due to reduced bark beetle habitat suitability at low stand densities

BARK BEETLE HAZARD in PONDEROSA PINE – Low/Moderate Pressure (BB_PP_SDI_HAZ_LM_PRES) using SDI

Evaluation Criteria:

1. If no PP is present (any size) but "forested", then VERY LOW SUSCEPTIBILITY (0)
2. If total stand BA (all species, all sizes) (**TBA**) is <40ft2, then LOW SUSCEPTIBILITY (1)
3. If **% host BA** (*defined as PP>=5"DBH / total stand BA of all species and sizes*) is <25%, then LOW SUSCEPTIBILITY (1)
4. If PP "**size**" is <5" (*calculated as BAwtDBH of PP of all sizes or QMD of PP >=5" DBH*), then LOW SUSCEPTIBILITY (1)
5. If **% host BA** is >=25% and PP "**size**" is >=5", then hazard assignment by SDI:
    - If SDI <= 208 (all species, all sizes), then LOW SUSCEPTIBILITY (1)
        - defined as having >=85% probability of <=10% mortality or [>=90% survivorship] during severe outbreak/BB population pressure
    - If SDI >208 (all species, all sizes), then MODERATE SUSCEPTIBILITY (2)
        - defined as having >=85% probability of <=30% mortality or [>=70% survivorship] during severe outbreak/BB population pressure
    - *With Low/Mod beetle pressure no stands of PP (or other yellow pines) are HIGH SUSCEPTIBILITY (3) (i.e. none expected to have >=85% probability of >30% mortality [or <70% survivorship] during severe outbreak/BB population pressure*

The simplified representation of this is:

- If no PP is present (any size) but "forested", then VERY LOW SUSCEPTIBILITY (0)
- If **% host BA** (*defined as PP>=5"DBH / total stand BA of all species and sizes*) is >=25% and PP "**size**" (*calculated as BAwtDBH of PP of all sizes or QMD of PP >=5" DBH*) is >=5" and SDI (all species, all sizes) is > 208, then MODERATE SUSCEPTIBILITY (2)
- Otherwise, LOW SUSCEPTIBILITY (1)
- *There is no HIGH SUSCEPTIBILITY (3) for the low-moderate pressure scenario!*

SDI Hazard Rating Criteria for Bark Beetles in Ponderosa Pine assuming Low-Moderate Pressure[1]

Criteria	Attribute	Very Low	Low	Low	Low	Moderate	High
Step 1	% of total stand BA that is ponderosa pine ≥5" DBH	0	<25% of BA *[but species present, any size]*	≥25% *OR* <5"	≥25% AND ≥5"		*There is no HIGH for the low-moderate outbreak situations!*
Step 2	QMD of PP ≥5" DBH Or BAwtDBH of all PP						
Step 3	SDI of all trees in stand				≤ 208	>208	

[1]For stands/plots with < 40 ft^2 total BA, hazard is rated as 'Low' due to reduced bark beetle habitat suitability at low stand densities

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